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## The Physiological Mechanisms by which Exercise Improves Sleep Quality

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## The Physiological Mechanisms by which Exercise Improves Sleep Quality

### *Purpose/Background*

Adequate sleep and exercise are essential factors that improve our daily and overall lifestyle. Over 70% of adults report lack of sleep in the United States (Wang & Youngstedt, 2014). Both lack of sleep and minimal exercise lead to chronic health problems such as heart disease, obesity, and diabetes (Wang & Youngstedt, 2014). College students and adults do not always prioritize sleep and exercise. However, exercise is used as a coping mechanism for stressors which also positively affects our sleep quality (Wunsch, Kasten, & Fuchs, 2017). A study by Wunsch et al. focused on physical activity's impact on college students in high academic stress periods through a series of surveys, and they concluded that participating in exercise diminished feelings of stress (2017). The participants that exercised and presented lower stress levels also reported a higher level of sleep quality compared to those who did not exercise (Wunsch et al., 2017). Today, numerous people are also exploring various non-pharmacological and holistic methods to improve their health (Cole, 2005). Beneficial non-pharmacological mechanisms that can improve overall health include an increase in exercise frequency and sleep quality/duration (Cole, 2005). Lastly, people strive to increase their exercise performance as well as improve their sleep quality to improve their mood, anxiety, memory, and overall physique (Rayward, Burton, Brown, Holliday, Plotnikoff, & Duncan, 2018). It is important to understand the underlying physiological mechanisms of increased sleep quality following exercise to combat health complications in future generations. I am going to uncover the physiological mechanisms by which exercise improves sleep quality.

### *Sleep Background*

Understanding the processes that occur during sleep is essential in determining how exercise impacts sleep. Sleep consists of non-rapid eye movement (NREM) and rapid eye movement (REM) periods (Siegelbaum & Hudspeth, 2013). NREM sleep is broken down into four stages (Figure 1). Stage one of NREM is the period between wakefulness and sleep; there is a decrease in brain activity (Siegelbaum & Hudspeth, 2013). Stage two of NREM is characterized by slow synchronized fluctuations of neuronal activity in the thalamus and cerebral cortex (Purves, Augustine, Fitzpatrick, Hall, LaMantia, & White, 2012). This stage consists of relaxation, decreased muscle tone, and a slowed rate of respiration (Siegelbaum & Hudspeth, 2013). Stage three NREM consists of decreased arousal and increased synchronization of thalamic and cortical activity in the brain (Purves et al., 2012); this is the first stage of “deep sleep”. With stage four NREM, a deep state of relaxation that consists of a low heart rate, low muscle tone, and a slow respiration rate (Siegelbaum & Hudspeth, 2013). REM is a much different state of sleep compared to NREM sleep. REM electroencephalogram (EEG) readings show that brain activity is similar to wakefulness due to vivid dreams (Siegelbaum & Hudspeth, 2013). REM periods become longer throughout the night (Purves et al., 2012). Sleep plays a vital role in recovery after exercise (Patrick, Lee, Raha, Pillai, Gupta, Sethi, Mukeshimana, Gerard, Moghal, Saleh, Smith, Morrell, & Moss, 2017).

Adequate sleep is vital for tissue and muscle recovery, particularly following exercise. Tissue repair during sleep allows for energy restoration and muscle growth (Siegelbaum & Hudspeth, 2013). During slow wave sleep (stages 3 and 4) growth hormone, an anabolic hormone, is released to promote protein synthesis for tissue and muscle recovery (Siegelbaum & Hudspeth, 2013). Lack of sleep can have several implications; In a review article, Leproult and

Van Cauter concluded that lack of sleep promotes insulin resistance and reduced testosterone in adults (2009). Minimal sleep increases cortisol concentrations, a catabolic hormone, which alter growth hormone and testosterone levels (Leproult & Van Cauter, 2009). Therefore, proper amounts of sleep to aid recovery is vital to trigger anabolic hormones and decrease catabolic hormone concentrations (Brooks, Fahey, & Baldwin, 2005). A study conducted by Patrick et al. (2017) tested academic performance and physical activity in sleep deprived and non-sleep deprived college students. Students were separated into sleep deprived and non-sleep deprived groups. The following day, they tested reaction time, heart rate, blood pressure, as well as memory tasks. The students who were sleep deprived had an increase in systolic blood pressure and a decreased reaction time during exercise (Patrick et al., 2017). Participants in another study participated in a combined intervention aerobic exercise program where they learned about the positive impacts of exercise on sleep and exercised aerobically three times per week (Erlacher, Erlacher, & Schredl, 2015). They concluded that moderate exercise and sleep education over a four-week period decreased heart rate and blood pressure during sleep and after exercise (Erlacher et al., 2015). Sleep is important for recovery, but exercise has been shown to be vital in improving the amount of slow wave sleep which aids in the recovery process.

### *Exercise Background*

There are different intensities and types of exercise that must be examined to understand the improvements in slow wave sleep, which will in turn improve sleep quality. One study focused on various exercise intensities and how the intensity changed the amount of time in different stages of sleep (Dworak, Wiater, Alfer, Stephan, Hollmann, & Struder, 2008).

Adolescent-aged subjects cycled at a moderate and high heart rate for 30 minutes (Dworak et al., 2008). Each trial was separated by one week, and polysomnographic activity was used to

determine the results by measuring sleep cycles. They found that high intensity exercise has been shown to increase the amount of time spent in slow wave sleep while maintaining the amount of REM sleep (Figure 2). It is advantageous to have less stage one and two sleep because it is not a deep sleep and does not aid in energy restoration or tissue recovery (Dworak et al., 2008). This evidence concludes that intensity is an important component in the mechanisms by which exercise improves sleep quality (Roveda, Sciolla, Montaruli, Calogiuri, Angeli, & Carandente, 2011). High intensity exercise enables certain physiological processes to be triggered to increase slow wave sleep, therefore improving sleep quality.

Type of exercise can be broken down into two categories, anaerobic and aerobic. Anaerobic exercise tends to utilize the creatine phosphate and glycolytic pathways to make ATP because it consists of short bursts of high intensity exercise. The creatine phosphate pathway is efficient, however it produces minimal net ATP, whereas the glycolytic pathway takes a greater amount of time to create ATP, but there are more net ATP produced (Brooks et al., 2005). In contrast, aerobic exercise primarily uses oxidative phosphorylation as an ATP source because it includes low to moderate intensity exercise over a longer period of time (Brooks et al., 2005). Oxidative phosphorylation is the energy system that takes the longest to produce ATP, however it produces the most net ATP (Brooks et al., 2005). One study found that one session of high intensity (aerobic and anaerobic) training in the morning increases the quantity and quality of sleep in highly trained cyclists (Roveda et al., 2011). After a baseline VO<sub>2</sub>max, the subjects performed the two different exercise (weight lifting and running) trials at 80% of their VO<sub>2</sub>max for thirty minutes, and the researchers used an actigraph to measure sleep quality (Roveda et al., 2011). This study only measured the acute effects of exercise on sleep quality; they measured sleep for two nights following exercise (Roveda et al., 2011). The quality of sleep only

significantly improved the night after exercise (Figure 3). The type of exercise did not change the sleep quality of the participants, and intensity was shown to be the largest determinant of sleep quality (Roveda et al., 2011). Another study focused on the long-term impacts of sleep after aerobic and anaerobic exercise. Over a ten-week period, participants were assigned an exercise group (aerobic or anaerobic), and they were required to exercise three times each week (Toktam, Ali, Fahimeh, & Saman, 2017). They used a VO2max test to determine 95% of their maximum for the anaerobic group and 70% of their maximum for the aerobic group. The Pittsburgh Sleep Quality Index (PSQI) was used to determine their perceived sleep quality (Toktam et al., 2017). The results concluded that both anaerobic and aerobic exercise significantly improved long-term sleep quality (Table 1). Researchers have determined that the type of exercise performed does not matter; intensity is the determinant (Brooks et al., 2005). High intensity anaerobic or aerobic exercise can improve sleep quality through several different mechanisms.

### *Mechanisms*

Exercise disturbs homeostasis through various mechanisms. Researchers have discovered several acute and chronic ways that exercise improves sleep quality, however they are still uncovering the direct pathways of how these mechanisms aid in sleep quality improvements. There are various mechanisms that aid in exercise to improve sleep, and there is not one mechanism that explains it all. Changes in temperature, hormones, and heart rate after exercise are a few mechanisms to explore because they have been shown to improve sleep quality.

#### *1. Temperature*

Exercise increases core temperature acutely as well as skin temperature (Brooks et al., 2005). However, before and during sleep body temperature drops (Horne & Staff, 1983). A study completed by Horne and Staff (1983) found that increases in core temperature via high intensity

aerobic exercise and phasic heating (submersion in hot water for 30 minutes) in trained individuals increased the time in stage three and four NREM sleep. Low intensity exercise did not show an increase in slow wave sleep (Horne & Staff, 1983). High intensity exercise increases the amount of time in slow wave sleep; therefore, body temperature is able to decrease further to trigger energy restoration (Table 2). The further drop in body temperature is advantageous because it conserves energy by lowering metabolism rates and allowing the body to fully relax.

### *1. Hormones*

High intensity exercise increases the activity of anabolic hormones. Testosterone, growth hormone, and insulin-like growth factor are three hormones that are triggered with exercise (Brooks et al., 2005). Testosterone not only initiates protein synthesis to promote muscle hypertrophy, but it also improves sleep quality (Leproult & Van Cauter, 2011). Low levels of sleep are associated with low testosterone concentrations (Leproult & Van Cauter, 2011). Frequent high intensity exercise increases resting testosterone levels which will also improve sleep quality (Brooks et al., 2005). Growth hormone is also triggered with moderate to high intensity exercise (Brooks et al., 2005). Kanaley, Weltman, Veldhuis, Rogol, Hartman, & Weltman (1997) examined growth hormone with repeated sessions of high intensity aerobic exercise and no exercise. They found that there was greater growth hormone release during sleep with exercise than the no exercise condition (Kanaley et al., 1997). Growth hormone is released during slow wave sleep, therefore there may be a correlation between more growth hormone release and longer slow wave sleep. It is released from the anterior pituitary gland and increases triglyceride breakdown and stimulates release of insulin-like growth factor from the liver (Brooks et al., 2005). In contrast, cortisol, a catabolic hormone, increases with lack of sleep (Brooks et al., 2005). Cortisol blocks protein synthesis and combats recovery and muscle

hypertrophy (Brooks et al., 2005). To maintain anabolic processes and decrease catabolic processes, sleep and exercise must be consistent; there is a bidirectional association with sleep and exercise (Shah, Rice, Tracy, Rohan, Bůžková, Newman, & Kaplan, 2013). In a bidirectional study conducted by Rae, Chin, Dikgomo, Hill, McKune, Kohn, & Roden (2017), the subjects performed high intensity interval training in a sleep deprived state and a non-sleep deprived state. They concluded that the subjects that received limited amounts of sleep had increased cortisol levels, blood pressure, significantly decreased peak power output, and plummeted motivation levels. Hormonal concentration levels can impact recovery, performance, and mood.

## *2. Heart Rate and Heart Rate Variability*

Researchers know that exercise acutely and chronically changes heart rate and heart rate variability, but they are continuing to unfold the direct relation to improvements in sleep. Exercise increases heart rate which also increases cardiac output. Cardiac output and heart rate increase with exercise because the muscles need oxygenated blood at a faster rate to continue exercising and produce more force (Davies, 2018). The increased rate of cardiac output is influenced by heart rate and stroke volume (McKinley et al., 2018). The heart must pump blood throughout the body at a faster rate by elevating heart rate (Davies, 2018). A frequent exercise routine will increase the size of the heart muscle. A larger heart muscle increases cardiac output and stroke volume; therefore, the heart does not need to beat as often (Brooks et al., 2005). Also, short or long-term exercise enhances vagal modulation, which results in bradycardia after exercise (Uchida, Shioda, Morita, Kubota, Ganeko, & Takeda, 2012). The increase in vagal modulation would lead to parasympathetic dominance which will improve sleep quality by increasing heart rate variability and decreasing heart rate during stage three of NREM sleep (Uchida et al., 2012). Therefore, decreasing the heart rate in slow wave sleep will increase the



time in this stage. However, there has been mixed findings on how heart rate and heart rate variability are impacted during sleep depending on the time of day that exercise is performed.

### *Research Proposal*

The physiological mechanisms by which exercise affects sleep quality may differ depending on what part of the day exercise is performed (Roveda et al., 2011). To improve sleep high intensity anaerobic or aerobic exercise is beneficial (Toktam et al., 2017). However, research findings have varied depending on the time of day that exercise is performed. Surprisingly, a study that tested different exercise intensities in the evening found that heart rate was increased during sleep, which did not lead to an increase in slow wave sleep and decreased sleep quality (Myllymäki, Rusko, Syväoja, Juuti, Kinnunen, & Kyröläinen, 2012). However, Roveda et al. found that exercise at a high intensity in the morning decreased heart rate throughout the day and during sleep, which increased sleep quality (2011). Actigraph activity was used in both studies to determine sleep quality after exercise. Researchers have not investigated or compared the time of day that exercise is performed and how the time of day that one exercises changes sleep quality. With the conflicting views and little research provided, it is important to understand the how morning versus night exercise effect sleep quality.

The purpose of this study is to determine if the time of day that exercise is performed changes the mechanisms by which exercise improves sleep quality by changes in nocturnal heart rate. I hypothesize that exercising in the morning will have a positive effect on sleep quality through decreased nocturnal heart rate and exercise at night will not alter nocturnal heart rate or sleep quality.

### *Subjects*

The subjects will consist of 20 male and female college students. They must perform recreational exercise three to five times per week and have no injuries that impair their physical function in the past six months.

### *Methods*

Prior to all testing, subjects are not allowed to eat or drink anything except water for eight hours to eliminate dietary influences. First, subjects will fill out the Pittsburgh Sleep Quality Index Survey (PSQI) for two nights with no prior exercise for 48 hours. The PSQI determines their perceived sleep without exercise. During these 48 hours, heart rate and actigraph activity will also be measured. Next, subjects will perform a baseline VO<sub>2</sub>max test on the treadmill to determine their heart rate at 80% of their VO<sub>2</sub>max. This is the intensity that the subjects will work at during the following sessions. During the VO<sub>2</sub>max test, the subjects will choose a speed that they are comfortable running at for an hour. Every three minutes, the treadmill grade will increase by 2.5%, but the speed will stay consistent. The subjects will run until they are unable to continue.

After the baseline tests, the subjects will be randomly divided into two groups. The first group will perform a 30-minute run on the treadmill at 80% of their VO<sub>2</sub>max in the morning (between 7:00 AM and 11:00 AM) one week after the non-exercising trial. The second group performs the same procedure in the evening (between 7:00 PM and 11:00 PM). During the exercise sessions, heart rate will be continuously measured to determine if they are working at 80% of their maximum. The subjects will wear a heart rate monitor across their chest and on their wrist to ensure accuracy. The subjects will repeat the procedure at the other time of day one week after the first trial.

Sleep will be measured through two different methods. The subjects will continue to wear the heart rate monitors for 48 hours following both exercise sessions. An actigraph that consists of Actiwatch Activity and Sleep Analysis 5 (version 5.32, Cambridge Neurotechnology Ltd, Cambridge, UK) will be worn to measure restlessness, amount of sleep, percentage of time asleep, and amount of activity bouts during sleep the night following exercise.

### *Analysis*

Statistical analysis will be determined using a paired t-test to compare the results for each subject in the various trials. It will determine if a significant difference was present with heart rate and actigraph activity for the two separate trials. Statistical significance will be set to  $p < 0.05$ .

### *Expected Results*

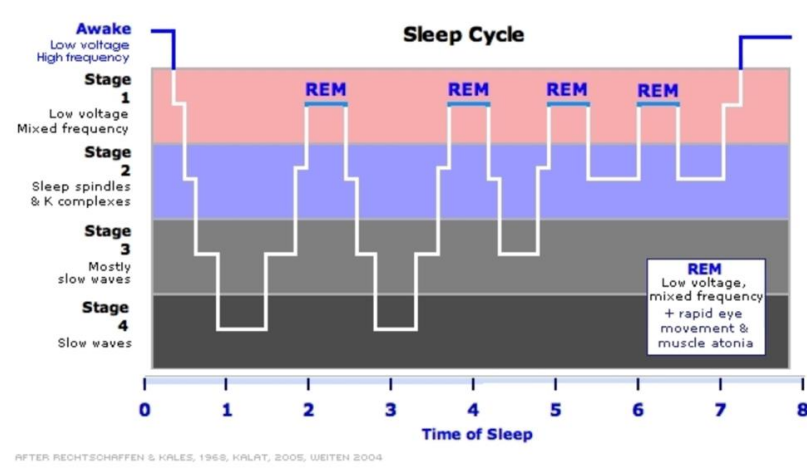
I suspect the results would support the hypothesis. Exercising in the morning would have a statistically significant improvement in sleep quality associated with a decreased resting heart rate and longer period of slow wave sleep, whereas exercising in the evening would not improve sleep quality and nocturnal heart rate. High intensity exercise in the evening would increase nocturnal heart rate, which would make it more difficult to maintain a lower heart rate while sleeping. However, exercise in the morning would increase heart rate in the early part of the day, but it would return to baseline and would drop before falling asleep and during sleep. Frequent exercise can eventually lower resting heart rate, which can create an increased amount of slow wave sleep and improve sleep quality (Myllymäki et al., 2012). Actigraph activity would show a decrease in restlessness, increase in amount of sleep, increase in percentage of time asleep, and a decrease in amount of activity bouts during sleep the night after morning exercise. Actigraph activity would be similar in the no exercise and evening exercise conditions. In all three

conditions, there would most likely be no significant change in actigraph activity the second night after exercise because the subjects would not perform exercise during the second day.

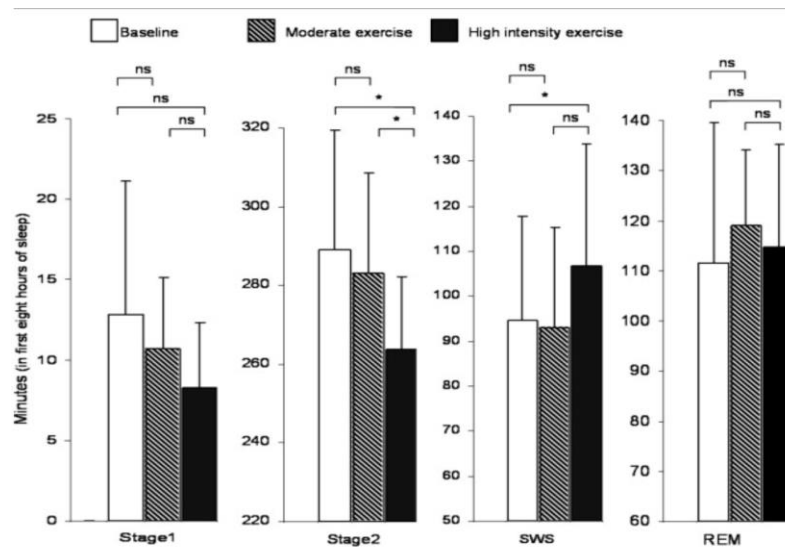
### *Discussion*

Better sleep quality leads to decreased risk of cardiovascular disease, diabetes, obesity, and several other health concerns (Wang & Youngstedt, 2014). It is important that we combat these life-threatening diseases by understanding which part of the day is best to exercise to improve sleep quality and overall health. There are some limitations to this proposed study. The subject population may serve as a limitation; the subjects are a group of college students which does not directly relate to others who have sleep disorders such as insomnia or sleep apnea. Also, hormones, core temperature, and other mechanisms may also play a vital role in determining which part of the day people should exercise to improve sleep quality. There are various physiological mechanisms by which exercise improves sleep quality, and we must take all of them into consideration. Once heart rate is evaluated, these other factors are important to consider. This is an acute protocol; therefore, we will be unable to determine if the body is able to adapt to morning or evening exercise and change the effects on sleep quality over time. However, this study would be a beneficial way to understand if the time of day that one exercises changes their sleep quality due to changes in nocturnal heart rate and actigraph activity.

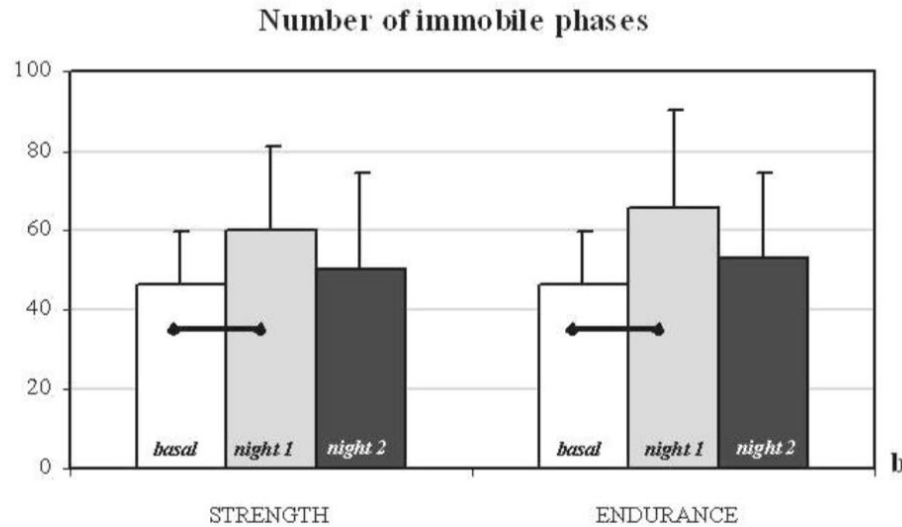
Tables and Figures



**Figure 1.** *Sleep Cycle.* This figure represents the various stages of NREM and REM sleep. It shows brain activity throughout an eight-hour sleep cycle (Cooper, 2014).



**Figure 2.** *Different Exercise Intensities and Their Impact on Different Stages of Sleep.* The duration of sleep is fixed at eight hours, and the minutes in each sleep stage is shown. High intensity exercise has the highest number of minutes in SWS (slow wave sleep).



**Figure 3.** *Number of Immobile Phases with High Intensity Strength and Endurance Exercises.* In a study by Roveda et al. (2011), they observed the acute effects of strength and endurance exercises on sleep quality. There was a significant improvement in sleep quality following both conditions ( $p < 0.05$ ).

**Table 1.** *Sleep Quality Outcomes After Ten Weeks of Aerobic, Anaerobic, or No Exercise.* This study was conducted by Toktam et al. (2017), and they found that sleep quality increased using the PSQI with long-term aerobic and anaerobic exercise ( $p < 0.001$ )

Sleep quality	Group			$P^b$
	Aerobic	Anaerobic	Control	
Before	$4.06 \pm 3.62$	$4.56 \pm 4.93$	$4.50 \pm 4.01$	0.98
After	$2.30 \pm 2.96$	$1.96 \pm 3.60$	$4.66 \pm 4.16$	0.008
$P^c$	<0.001	<0.001	0.023	

**Table 2.** *Sleep Stage Data.* This table consists of different conditions (baseline, low intensity, high intensity, phasic heating) and the amount of time in different stages of sleep. It is important to note the amount of SWS.

**TABLE 2.** *Sleep stage data (means and standard deviations in min) for 450-min sleep period time from sleep onset, with significance levels*

	Baseline	LI	HI	PH
Wake + stage 1	17.4 (14.6)	17.2 (14.2)	19.5 (12.3)	15.1 (10.7)
Stage 2	221.3 (10.5)	236.4 (32.4)	219.2 (24.4)	220.0 (17.2)
Stage 3	35.4 (8.1)	35.1 (7.9)	43.2 (11.9) <sup>ae, ce</sup>	35.6 (11.5)
Stage 4	40.2 (18.9)	39.9 (19.1)	45.7 (23.0)	58.0 (19.1) <sup>af, ce</sup>
Stages 3 + 4 (SWS)	75.6 (17.4)	75.0 (23.3)	88.9 (22.0) <sup>ae</sup>	93.6 (16.0) <sup>af</sup>
Stage REM	136.0 (16.8)	121.5 (26.7)	122.0 (19.9)	121.1 (21.1)

For footnotes, see Table 1.

#### References:

- Brooks, G. A., Fahey, T. D., & Baldwin, K. M. (2005). *Exercise Physiology: Human bioenergetics and its applications* (4th ed.). New York, NY: McGraw-Hill Companies.
- Cole, R. J. (2005) Nonpharmacologic techniques for promoting sleep. *Clinics in Sports Medicine*, 24(2), 343-353.
- Cooper, T. (2014). Understanding sleep for optimal recovery & productivity. Retrieved from <https://www.catalystathletics.com/article/1845/Understanding-Sleep-for-Optimal-Recovery-Productivity/>
- Davies K. (2018). Cardiovascular adaptive homeostasis in exercise. *Frontiers in Physiology*, 9, 369. doi:10.3389/fphys.2018.00369

- Dworak, M., Wiater, A., Alfer, D., Stephan, E., Hollmann, W., Struder, H. (2008). Increased slow wave sleep and reduced stage two sleep in children depending on their exercise intensity. *Journal of Sleep Medicine*, 9(3).
- Erlacher, C., Erlacher, D., & Schredl, M. (2015). The effects of exercise on self-rated sleep among adults with chronic sleep complaints. *Journal of Sport and Health Science*, 4, 289-298.
- Kanaley, J. A., Weltman, J. Y., Veldhuis, J. D., Rogol, A. D., Hartman, M. L., Weltman, A. (1997). Human growth hormone response to repeated bouts of aerobic exercise. *Clinical Neurophysiology*. 83, 1756–1761
- Leproult, R., & Van Cauter, E. (2011). Effect of 1 week of sleep restriction on testosterone levels in young healthy men. *JAMA*, 305(21), 2173-4.
- Leproult, R., & Van Cauter, E. (2009). Role of sleep and sleep loss in hormonal release and metabolism. *Endocrine development*, 17, 11-21.
- McKinley, M. P., O'Loughlin, V. D., & Bidle, T. S. (2018). *Anatomy & physiology: An integrative approach* (3rd ed.). New York, NY: McGraw-Hill Companies.
- Myllymäki, T., Rusko, H., Syväoja, H., Juuti, T., Kinnunen, M.-L., & Kyröläinen, H. (2012). Effects of exercise intensity and duration on nocturnal heart rate variability and sleep quality. *European Journal of Applied Physiology*, 112(3), 801–809.
- Patrick, Y., Lee, A., Raha, O., Pillai, K., Gupta, S., Sethi, S., Mukeshimana, F., Gerard, L., Moghal, M. U., Saleh, S. N., Smith, S. F., Morrell, M. J., & Moss, J. (2017). Effects of sleep deprivation on cognitive and physical performance in university students. *Sleep and Biological Rhythms*, 15(3), 217-225.



- Purves, D., Augustine, A. J., Fitzpatrick, D., Hall, W. C., LaMantia, A., & White, L. E. (2012). *Neuroscience* (5th ed.). Sunderland, MA: Sinauer.
- Rae, D., Chin, T., Dikgomo, K., Hill, L., McKune, A., Kohn, T., & Roden, L. C. (2017). One night of partial sleep deprivation impairs recovery from a single exercise training session. *European Journal of Applied Physiology*, 117(4), 699–712.
- Rayward, A. T., Burton, N. W., Brown, W. J., Holliday, E. G., Plotnikoff, R. C., & Duncan, M. J. (2018). Associations between changes in activity and sleep quality and duration over two years. *Medicine & Science in Sports & Exercise*, 50(12), 2425–2432.
- Roveda, E., Sciolla, C., Montaruli, A., Calogiuri, G., Angeli, A., & Carandente, F. (2011). Effects of endurance and strength acute exercise on night sleep quality. *International SportMed Journal*, 12(3), 113–124.
- Semplonius, T., & Willoughby, T. (2018). Long-term links between physical activity and sleep quality. *Medicine & Science in Sports & Exercise*, 50(12), 2418–2424.
- Shah, N., Rice, T., Tracy, D., Rohan, T., Bužková, P., Newman, A., & Kaplan, R. C. (2013). Sleep and insulin-like growth factors in the cardiovascular health study. *Journal of clinical sleep medicine: JCSM: official publication of the American Academy of Sleep Medicine*, 9(12), 1245-51. doi:10.5664/jcsm.3260.
- Siegelbaum, S. A., & Hudspeth, A. J. (2013). *Principles of Neuroscience* (5th ed.) (E. R. Kandel, T. M. Jessell, & J. H. Schwartz, Eds.). New York, NY: McGraw-Hill Companies.
- Toktam, K., Ali, N., Fahimeh, A., & Saman, S. (2017). Comparing the effects of aerobic and anaerobic exercise on sleep quality among male nonathlete students. *Nursing and Midwife Studies*, 6(4), 168-173.

- Uchida, S., Shioda, K., Morita, Y., Kubota, C., Ganeko, M., & Takeda, N. (2012). Exercise effects on sleep physiology. *Frontiers in neurology*, 3, 48. doi:10.3389/fneur.2012.00048
- Wang, X., & Youngstedt, S. D. (2014). Sleep quality improved following a single session of moderate-intensity aerobic exercise in older women: Results from a pilot study. *Journal of Sport and Health Science*, 3, 338-342.
- Wunsch, K., Kasten, N., & Fuchs, R. (2017). The effect of physical activity on sleep quality, well-being, and affect in academic stress periods. *Nature and Science of Sleep*, 9, 117-126. doi:10.2147/NSS.S132078